

# **2005 Annual DOE Hydrogen Program Review Hydrogen Production & Delivery**

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# State of the Art

## Near-term technologies



- **Distributed Natural Gas Steam Methane Reforming:** \$4-5/gasoline gallon equivalent (gge) delivered
- **Electrolysis:** \$4.75 – 5.15/gge delivered



Sunline HyRadix Reformer



Giner PEM Electrolyzer



# DOE Hydrogen Production Technology Research Portfolio



## EERE

- Distributed natural gas and bio-derived liquid reforming
- Electrolysis
- Reforming biomass gas from gasification/pyrolysis
- Biological hydrogen production
- Photoelectrochemical hydrogen production
- Solar HT thermochemical cycles
- Separations



## Office of Fossil Energy

- Coal gasification with sequestration

## Office of Nuclear Energy

- Nuclear driven HT thermochemical cycles
- HT electrolysis

## Office of Science

- Basic research on materials and catalysts





# Hydrogen Production Barriers

## Cost and Energy Efficiency



### Distributed Reforming

#### Using Natural Gas and Renewable Liquids

- Intensified, lower capital cost, more efficient NG reformer technology
- Improved catalysts and technology for renewable liquid reforming
  - Ethanol, sugar alcohols, bio-oil

### Electrolysis

- Low cost materials and high efficiency system designs
- Integrated compression
- Integrated wind power/electrolysis systems

### Biomass Gasification

- Integrated gasification, reforming, shift and separations technology to reduce capital cost and improve efficiency.



H2Gen HGM 2000



NREL solar research  
Mesa top facility

### Solar/Photolytic

- Durable and efficient materials for direct photo-electrochemical solid state water splitting using sunlight
- Microorganisms that split water using sunlight or produce H<sub>2</sub> through fermentation
- Thermochemical cycles, solar concentrators, receivers/reactors to split water (600 – 2000 C)
  - Effective and efficient thermochemical cycles
  - Reduced capital cost of the solar concentrator



# New Hydrogen Cost Goal for 2015



- Pathway independent
- Consumer fueling costs are equivalent on a cents per mile basis
- Gasoline ICE and gasoline-electric hybrids are benchmarks
- Provide a "yardstick" for assessing technology performance



# Hydrogen Cost Goal for 2015



## Mechanics

$$\text{H2 Cost (\$/gge)} = (\text{EIA Projected Gasoline Price in 2015}) \left[ \frac{\text{Fuel Economy H2FCV}}{\text{Fuel Economy Competitive Vehicle}} \right]^1$$

Input	Value	Source
Gasoline price projection for 2015	\$1.26 / gal (untaxed, 2005 \$)	EIA Annual Energy Outlook, 2005
Ratio of FCV fuel economy to evolved gasoline ICE	2.40	NRC H2 Economy Report
Ratio of FCV fuel economy to gasoline hybrid	1.66	NRC H2 Economy Report

## Results

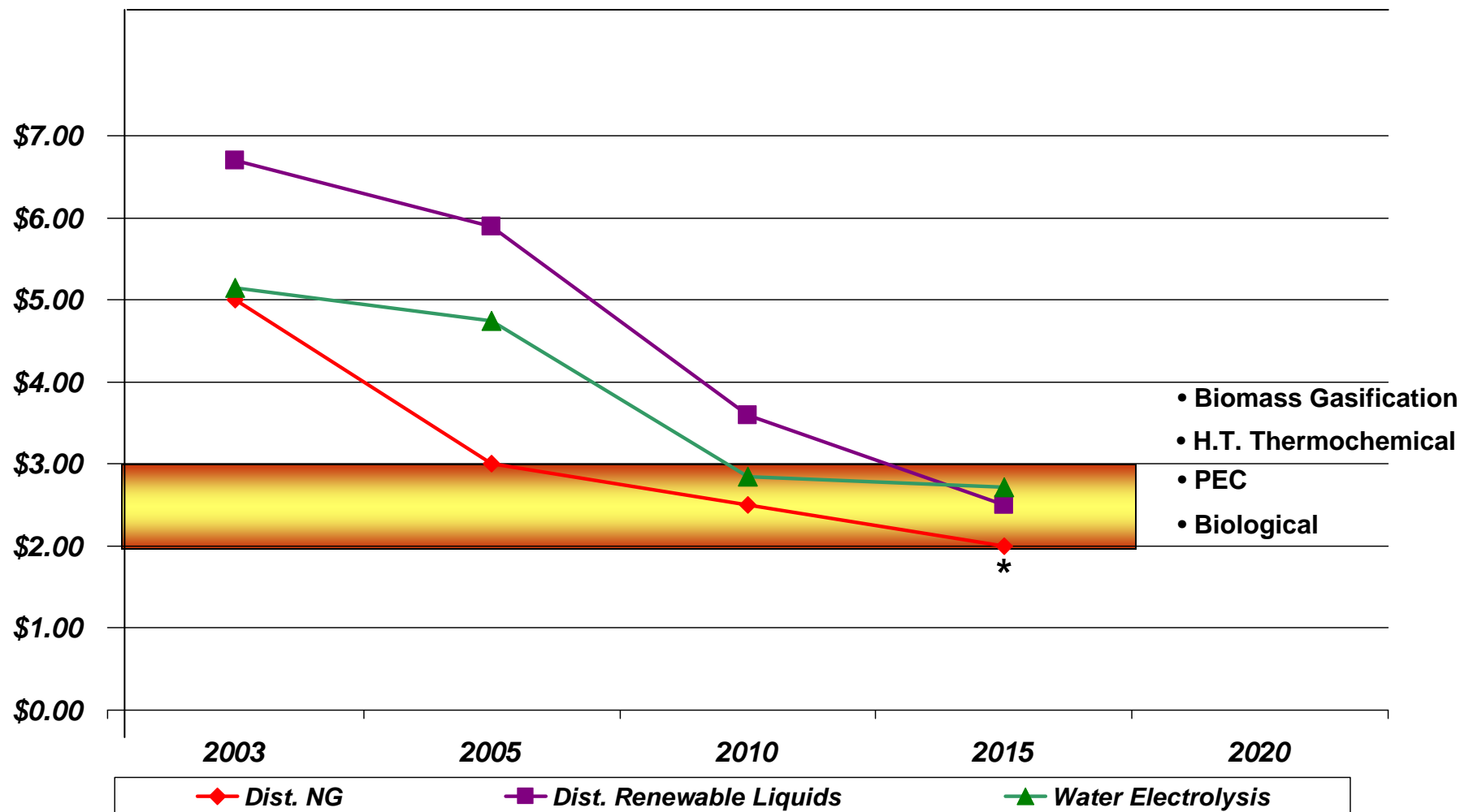
- \$ 2.00 - \$3.00 / gge\*

<sup>1</sup> Ratio of FCV fuel economy to competitive vehicle

\* Actual calculated values are \$2.09 and \$3.02 / gge



# Hydrogen Production Targets Compared to 2015 Cost Goal



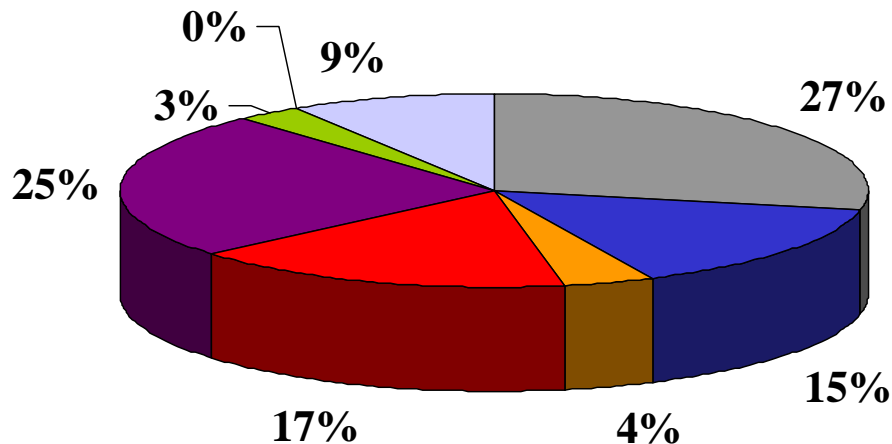
\* Pending final approval by DOE Change Control Board



# Hydrogen Production & Delivery Funding Distribution

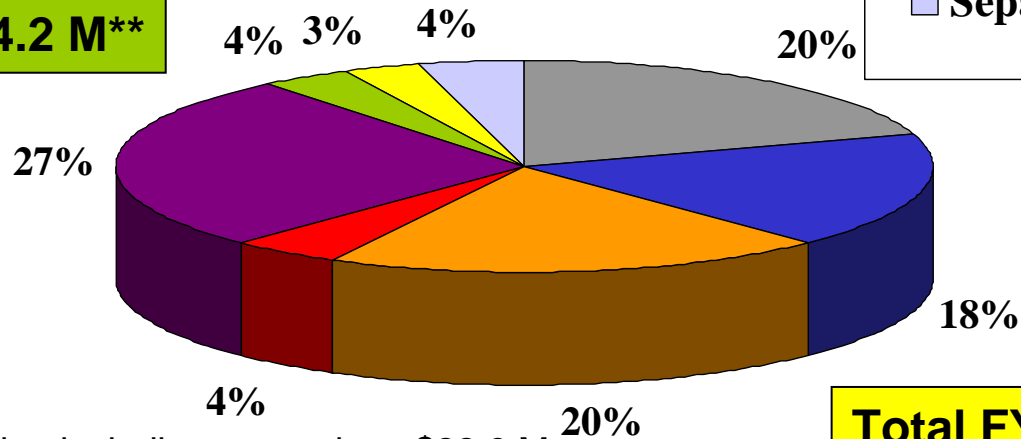


**FY 04 = \$10.3 M\***



- Distributed
- Reforming
- Electrolysis
- Delivery
- Analysis
- Bio & PEC
- Central Biomass
- Reforming
- Solar HT
- Thermochemical
- Separations

**FY 05 = \$14.2 M\*\***



**Total FY 06 Request = \$32.0 M**

\*FY 04 Appropriation including earmarks = \$22.6 M

\*\*FY 05 Appropriation including earmarks = \$25.3 M





# R & D Plan



## New goals and targets

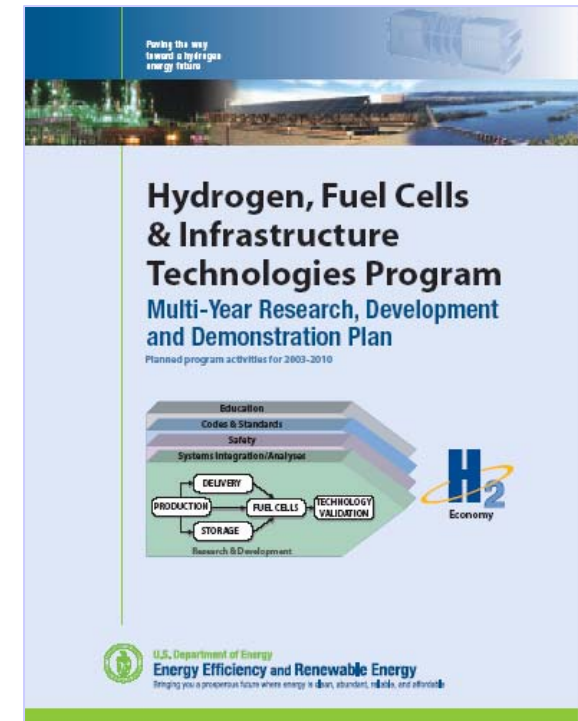
- Distributed renewable liquid reforming
- Water electrolysis from central renewables
- Separations technologies: dense metallic and microporous
- Biomass (gasification/pyrolysis) reforming
- Photosynthetic bacteria and dark fermentation

## Detailed target guidance

- Capital equipment targets separate from operations and maintenance
- Total system energy efficiency
- Specific capacity utilization factors

## Developed R & D targets based on common set of economic parameters

- 10% IRR after taxes, 100% equity financing, 1.9% inflation, 38.9% tax rate, 7 year depreciation





# Key Milestones



## FY 2008

- Go/No-go: Determine if membrane separation technology can be applied to natural gas distributed reforming during the transition to a hydrogen economy.
- Down-select to a primary technology and configuration for central biomass gasification/pyrolysis clean-up, reforming, shift, separations and purification.

## FY 2009

- Complete development of integrated “appliance” type distributed reforming system applying DFMA principles.

## FY 2010

- Go/No-Go: Identify cost-effective transparent H<sub>2</sub>-impermeable materials for use in photobiological and photoelectrochemical systems.
- Go/No-Go: Verify the feasibility of an effective integrated high-temperature solar-driven thermochemical cycle for hydrogen projected to meet the 2010 cost goal of \$6/gge (\$4/gge delivered by 2015).



# 2004 & 2005 DOE Hydrogen Production & Delivery Projects



## Distributed Production

MSRI  
GE Energy  
Air Products  
GTI  
PNNL  
Virent Energy Systems  
BOC Group, Inc.  
H2Gen Inno. Inc.  
GE Global Res.

## Separations

Eltorn Res. Inc.  
ORNL  
GTI

## Photobiological

U.C. Berkeley  
NREL  
ORNL  
J. Craig Venture Institute

## Biomass Reforming

United Tech. Res. Inst.

## H.T. Thermochemical

Univ. of Nevada

## Photoelectrochemical

U. of Hawaii  
NREL  
U. of Cal. Santa Barbara  
Midwest Optoelectronics  
GE Global Research  
SRI

## Electrolysis

Giner  
INEEL  
NREL  
Teledyne

## Delivery

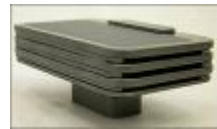
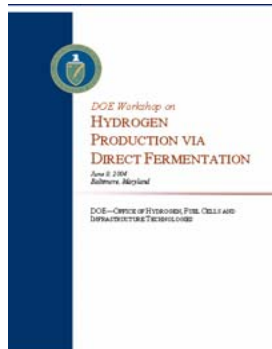
ANL  
ORNL  
Air Products  
Secat, Inc.



# Hydrogen Production R&D – Planning and Implementing



**Fermentation Workshop**



**Separations Workshop**

**Production & Delivery Selections Announced**

**Annual Program Review**

**H2A Tool**

**May '04 Jun '04**

**Sept '04**

**Oct '04**

**Nov '04**

**Feb '05**

**May '05**

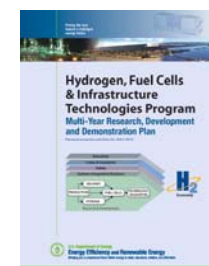


**Utility Electrolysis Workshop**

**Solar Electrolysis Workshop**



**R&D Plan Published**



**Opening Solid oxide Materials & Systems Development Solicitation**

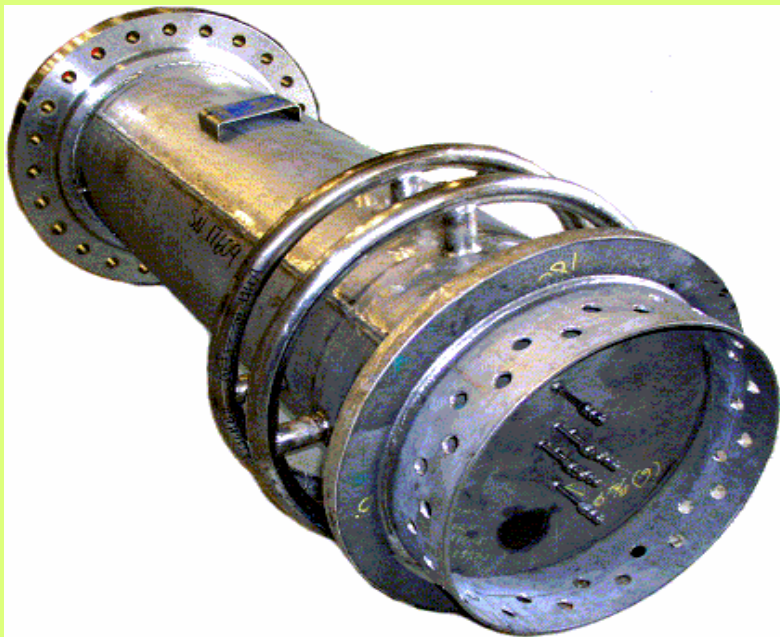


# Recent Technical Accomplishments



## Natural Gas Distributed Reforming

- Approaching R & D target of \$3/gge for distributed natural gas reforming at 5000 psi.



GE High-Pressure Autothermal Cyclic Reforming (ACR) Reactor



Teledyne HP TITAN™ HP generator

## Electrolysis

- Achieved 2000 psi H<sub>2</sub> production in planar electrolysis stack
- Developed new system designs with 40-50% part count reduction
- Novel stack design for alkaline system on track for achieving a hydrogen production cost of \$2.85/gge by 2010.





# Recent Technical Accomplishments



## Biological

- Increased photobiological efficiency of absorbed sunlight energy to ~15% (5% in 2003)
- 40-50% increase in oxygen tolerance achieved



Measuring photosynthetic productivity of micro-algae (NREL)



Lab scale testing of semiconductors (NREL)

## Photoelectrochemical

- Projected 1000 hours durability with new gallium phosphide nitride material for photoelectrochemical based on accelerated testing
- Integrated photovoltaic electrolysis panel ready for prototype testing



# Recent Technical Accomplishments



Biomass gasifier/pyrolyzer PDU (NREL)

## Biomass

### Gasification/Pyrolysis

- Developed biomass reforming catalyst to reduce coking and attrition

## Solar HT Thermochemical

- Demonstrated lab feasibility of zinc and manganese cycles
- Selected 4 groups of cycles
  - Volatile metal
  - Metal oxide
  - Sulfate
  - Sulfuric acid



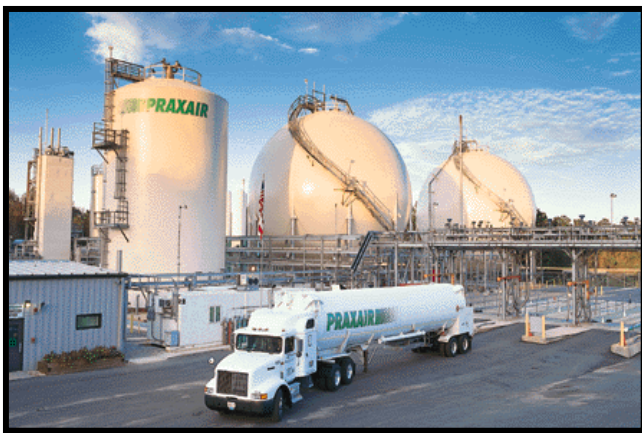
Solar HT Thermochemical reactor (NREL)



# Delivery State of the Art



- Today hydrogen is transported by cryogenic liquid trucks and gaseous tube trailers. There is also a very limited transmission pipeline infrastructure (630 miles; Gulf Coast, California, Chicago)
- Cost \$4-9/gge of H<sub>2</sub> or more depending on distance for truck transport. Pipeline transport can be <\$1/gge.







# Delivery Pathways and Components



## – Pathways

- Gaseous Hydrogen Delivery
- Liquid Hydrogen Delivery
- Carriers

} Including mixed pathways

## – Components

Pipelines

Compression

Liquefaction

Liquid and Gaseous

Storage Tanks

Carriers & Transformations

GH2 Tube Trailers

Terminals

Separations/Purification

Dispensers

Mobile Fuelers

Other Forecourt Issues

Cryogenic Liquid Trucks

Rail, Barge, Ships



# Delivery Barriers



## Analysis Needs

- Infrastructure options and trade-offs for the transition and long term

## Compression

### Transmission and Forecourt Applications

- Reliability
- Lower capital costs
- Energy efficiency

## Off-Board Storage

### Forecourt, Terminals, Other

- Lower cost (lower capital cost)
- Smaller footprint (Forecourt)

## Pipelines

- Hydrogen embrittlement and permeability
- Lower capital costs – new materials to reduce pipeline installation costs
- Coating – to allow usage of existing NG or other pipeline infrastructure or for new pipelines
- ROW
- Can we use existing NG infrastructure for mixtures if H<sub>2</sub> and NG?

## Liquefaction

- Higher energy efficiency – current technology consume >30% of H<sub>2</sub> energy
- Lower cost – current technology >\$/gge of H<sub>2</sub>

## Novel Carriers

- Discovery of novel solid or liquid carriers with sufficient H<sub>2</sub> density
- System energy efficiency and cost



# Delivery Objectives



- By **2007**, define the criteria for a cost-effective and energy-efficient hydrogen delivery infrastructure for the introduction and long-term use of hydrogen for transportation and stationary power.
- By **2010**, develop technologies to reduce the cost of hydrogen delivery from central and semi-central production facilities to the gate of refueling stations and other end users to **<\$0.90/gge** of hydrogen.
- By **2010**, develop technologies to reduce the cost of compression, storage, and dispensing at refueling stations and stationary power sites to less than **<\$0.80/gge** of hydrogen.
- By **2015**, develop technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to **<\$1.00/gge** of hydrogen<sup>19</sup> in total.



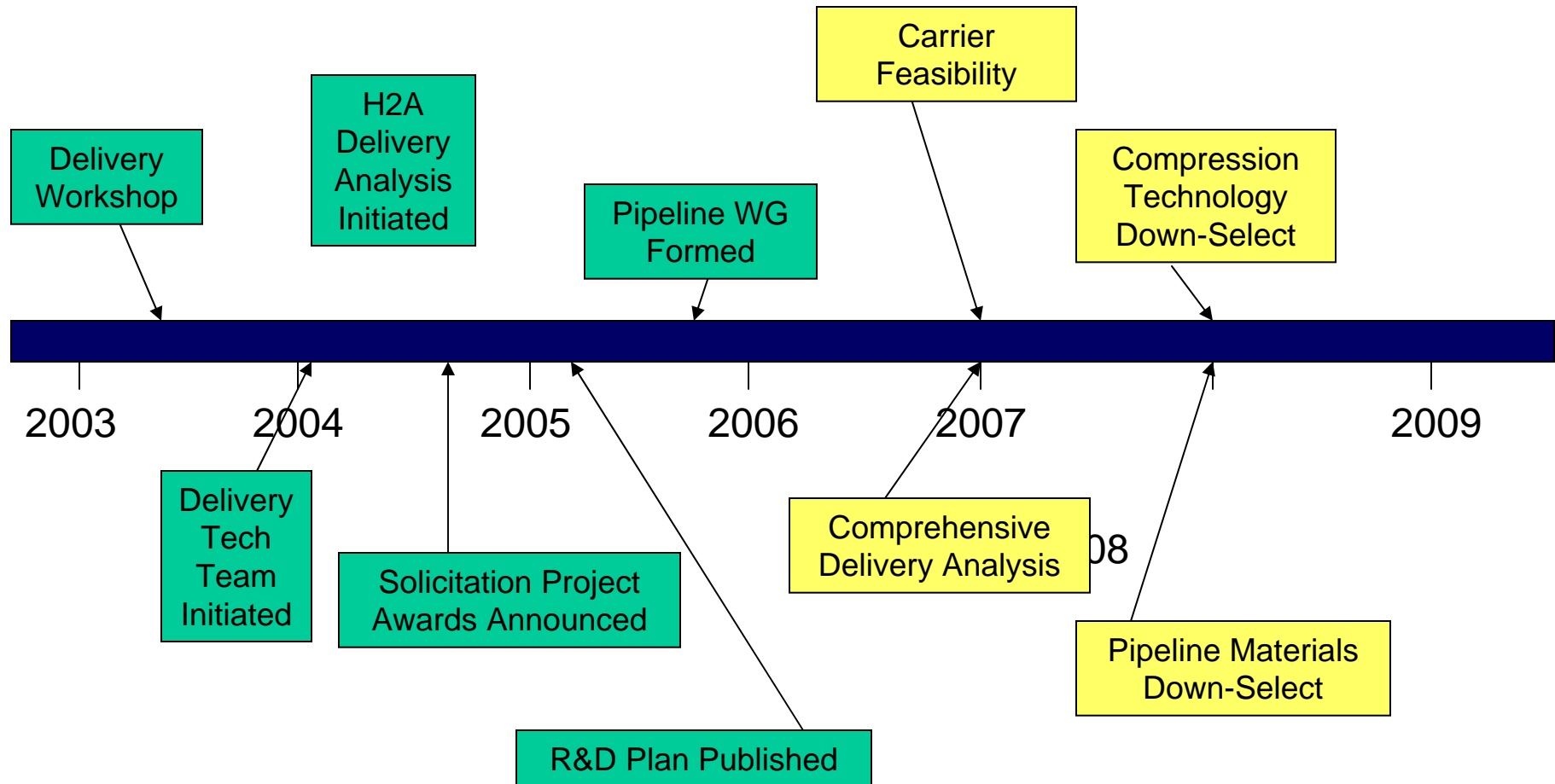
# Delivery Key Targets



Targets	2003 Status	2015 Target
Transmission Pipeline Capital (\$/mile)	\$1.20	\$0.80
Forecourt Compression		
Cost Contribution (\$/gge of H2)	\$0.60	\$0.25
Reliability	Unknown	>99%
Forecourt Storage Cost Contribution (\$/gge of H2)	\$0.70	\$0.20
Carrier (weight % H2)	3%	13%



# Delivery Planning and Implementation

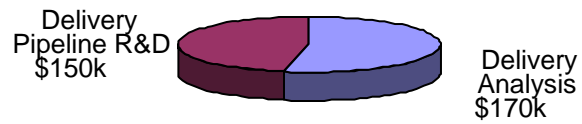




# Delivery Funding

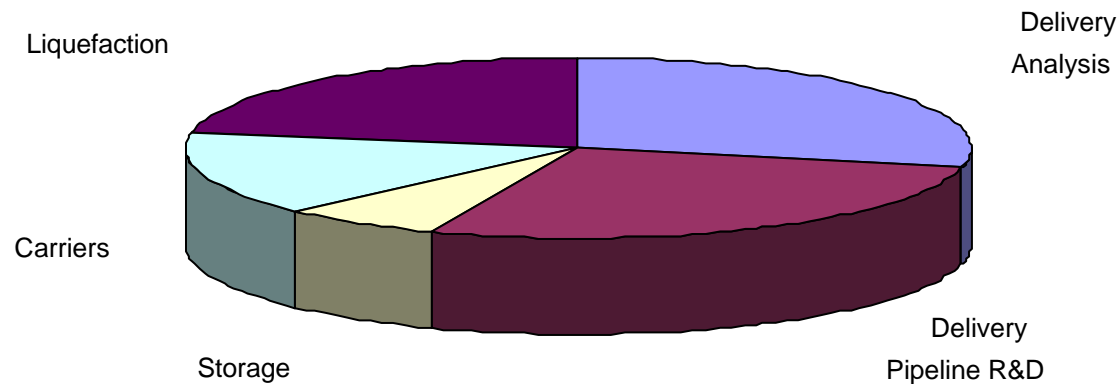


**FY04 Actual**



**Total=\$0.32M**

**FY05**



**Total= \$2.7 M**



# Delivery Key Accomplishments



- Delivery Tech Team and Draft Roadmap
- R&D Multi-Year Plan
- H2A Delivery Analysis Tools
  - Components and Scenarios
- Initial Portfolio of Research Projects
- Pipeline Working Group



# DOE Hydrogen Production Team



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